Proceedings: Volume II

TENTH
INTERNATIONAL
SYMPOSIUM
ON
ALCOHOL
FUELS

THE ROAD TO COMMERCIALIZATION

November 7-10, 1993

THE BROADMOOR HOTEL
COLORADO SPRINGS, COLORADO

DEMONSTRATION OF THE FUEL ECONOMY POTENTIAL OF A VEHICLE FUELED WITH M85

Shean P. Huff
Graduate Research Assistant
and
Jeffrey W. Hodgson
Professor

The University of Tennessee
Knoxville, Tennessee 37996-2210

Abstract

Most conversions of gasoline-fueled vehicles to operate on M85 result in the vehicle having improved power-related performance over the base vehicle. A study has now been completed in which a light duty vehicle fueled with M85 was modified to exploit the fuel economy potential rather than the performance potential of the fuel.

This was accomplished by decreasing the engine displacement and turbocharging it to maintain the same engine (and thus, vehicle) wide-open throttle performance. In order to reduce the number of extraneous variables affected, the displacement decrease was accomplished by converting the V-6 engine into a V-4 engine and retaining the original engine block. Other than the internal changes made to the engine, changes in materials necessary to accommodate the M85, and the necessary reprogramming of the engine control system, no other changes were made to the base vehicle.

Fuel economy testing revealed gasoline-equivalent fuel economy improvements of up to twenty-one percent at steady highway speeds and twenty percent on the EPA FTP-75 urban cycle. Suggestions for additional improvements are made.

DOE/CH10093-245
DE93018219
November 1993

Printed with renewable source ink on paper containing at least 50% wastepaper

DEMONSTRATION OF THE FUEL ECONOMY POTENTIAL OF A VEHICLE FUELED WITH M85

Introduction

The use of methanol fuels in light duty vehicles has energy security and air quality benefits that have led to its implementation -- particularly in California, where M85 (a mixture of 85 percent methanol and 15 percent unleaded gasoline, by volume) is available at public refueling stations. The substantial cooling effect created as methanol evaporates when mixed with the engine's intake air leads to increased power output from gasoline-fueled engines when they are converted to operate on methanol fuels (EPA 1989). If additional steps are taken to exploit the high octane rating of methanol fuels (typically, raising the engine's compression ratio and/or power boosting by turbocharging or supercharging), even higher power levels can be achieved.

Rather than accept the increased power levels as a benefit, the vehicle designer could, in theory, opt to implement the methanol conversion so that the increased power potential of the engine is used to realize improved vehicle energy efficiency rather than improved vehicle performance (acceleration potential). The trade-off between performance and fuel economy has been discussed elsewhere (Hellman 1986) and estimates have been made of the fuel economy of an "optimized" methanol vehicle (EPA 1989). These estimates, however, usually include "lean burn" concepts that may require advanced hardware or emission control strategies to implement. Figure 1, adapted from (EPA 1989), is an illustration of the type of thinking that has led to the claims of methanol's potential for improved fuel economy. This figure is apparently based on retaining a naturally aspirated engine concept.

In essence, the use of methanol fuels creates an opportunity to operate engines at high brake mean effective pressures (bmep). Since bmep can be expressed as brake torque per unit displacement, higher bmep's can be used to create higher torque from the same displacement (performance enhancement) or can be used to create the same torque using a smaller displacement engine (fuel efficiency enhancement).

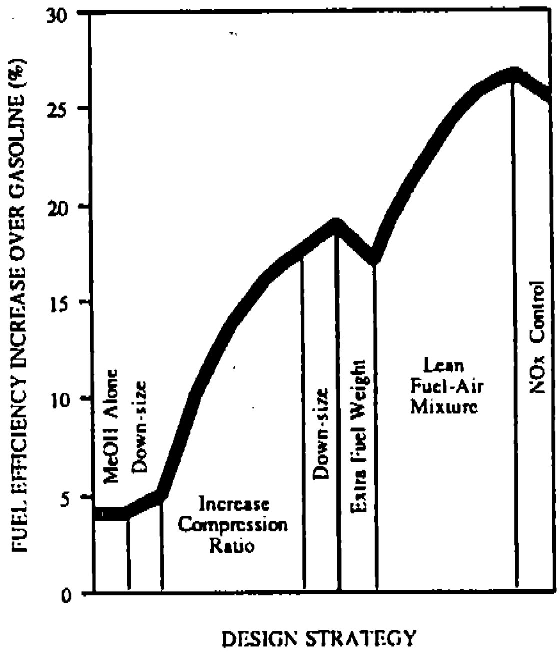

Figure 1. Fuel economy potential of methanol (EPA 1989)

The Concept

It was the objective of this study to demonstrate one way in which the potential for increased bmep resulting from methanol fuel use could be converted into improved vehicle fuel economy. The specific approach used was to take a given vehicle (1988 Chevrolet Corsica) with a V-6 engine and reduce the displacement of the engine by, in essence, "removing" two of the cylinders. The power output of the smaller methanol-fueled engine was made comparable to that of the larger gasoline-fueled engine by turbocharging the methanol engine. The smaller engine would have reduced mechanical friction because two of the cylinders were deactivated and, for a given engine speed and torque output (therefore, for a given brake power output) requirement, it would also have lower pumping losses because it would have to operate at a higher bmep and thus would require a higher intake manifold pressure (less throttling).

The obvious question is, "Why not simply install an existing four cylinder engine rather than modify the six cylinder engine?" The answer involves primarily the desire to explore the concept while changing as few variables as possible. If a different engine were used, questions would arise regarding the inherent differences in the two engine designs (combustion chamber shape, intake system design, control system, etc.). By using the same engine, these questions would be resolved. Another reason was that the particular vehicle used was equipped with an engine control system that was readily modified and the conversion to methanol fuel had already been accomplished.

The Approach

The test vehicle was a 1988 Chevrolet Corsica 4-door sedan equipped with a five-speed manual transmission and a V-6 push rod engine having a displacement of 2.8 liters. The engine had simultaneous double fire port fuel injection, direct fire ignition system, and the engine control system was based on the use of a mass air flow (MAF) sensor. This vehicle was originally supplied to the University of Tennessee by General Motors Corporation and was used by student teams in the 1989 Methanol Marathon and the 1990 Methanol Challenge competitions. As part of the competitions, General Motors provided methanol-tolerant fuel system components, high flow injectors, and instructions for modifying the various "look-up tables" in the engine control module (ECM). More detailed information regarding this vehicle is available in the literature (Hodgson 1990).

Following completion of the four-cylinder methanol tests, the engine was returned to its six-cylinder gasoline configuration for additional testing.

Mechanical Modifications

The 2.8 liter engine was modified by deactivating two cylinders. The cylinders chosen to be deactivated met the criteria that they should not be on the same cylinder bank and they should not be next to each other in the firing order. Thus, the effective displacement of the modified V-4 engine was 1.87 liters. The cylinders were deactivated by installing "dummy" valve lifters that did not contact the cam lobes. The use of "dummy" lifters was necessary to maintain oil pressure in the engine. Thermal expansion of the disabled valve train components was accommodated by installing springs between the rocker arms and the rocker arm retaining nuts.

While the original plan was to remove the pistons and connecting rods from the disabled cylinders, engine balancing considerations required retaining these and led to a different approach in which the piston rings were removed from the two pistons and large slots were machined in the piston crowns. The rings were removed to decrease the sliding friction between the pistons and the cylinder walls and the slots were introduced to allow the crankcase gases to pass freely back and forth past the piston. There was concern that merely removing the piston rings would create pumping losses if the pistons developed compression pressure as they traveled up the cylinder. To maintain the engine balance, the weight of the rings and the slot material removed was replaced by the addition of steel inserts in the hollow piston pins.

Control System Modifications

The control strategy for the Corsica engine is primarily based on engine speed and a load parameter (LV8) that is proportional to the mass flow rate of air divided by the engine speed. For a given engine, the LV8 parameter is proportional to the mass of air drawn into each cylinder on the intake stroke and thus the base injector pulse width is proportional to the LV8 value. In order to retain the value of this parameter when the engine was converted to four active cylinders, the scaling parameter of this variable was changed so that for a given mass flow rate of air the control system recognized that this air was being shared by four cylinders rather than six. That is, the "new" LV8 parameter was 1.5 times that of the "old" LV8 parameter.

The ignition timing used was not changed from that developed for the six-cylinder version of the engine and only minor changes were made in fuel metering to accommodate an injector change that became necessary during the study.

Power Boosting

In order to recover the wide-open-throttle power lost by downsizing the engine, it was fitted with a Garrett turbocharger. The unit used originally on the methanol-fueled six cylinder version was tried first, but proved to be a poor match in that boost was delayed until high engine speeds were encountered. The second unit used was similar to that used on a production 1.9 liter engine and it performed very well.

Emission Controls

The emission controls used on the conversion were the same as used in the six-cylinder methanol conversion (Hodgson 1990). These consisted of adding a close-coupled "light-off" catalyst between the engine and the stock catalyst and reprogramming the exhaust gas recirculation (EGR) schedule to yield a 40 percent decrease in the EGR rate.

It should be noted that other than the steps taken to deactivate the two engine cylinders, the changes made to accommodate the methanol fuel, and the installation of the turbocharger, no other modifications were made to the stock engine. Specifically, the stock camshaft, lifters and rocker arms were used, stock clearances were used in assembling the engine, and no "porting" or other modifications were made to the cylinder heads.

Testing

Several tests were conducted as part of the study. These included initial engine dynamometer tests, vehicle acceleration tests, vehicle emission tests, and vehicle fuel economy tests. Each is discussed below.

Dynamometer Testing

The engine was coupled to an electric d.c. dynamometer to determine the power output at wide-open-throttle. As was previously noted, the initial choice for a turbocharger proved to be inadequate and a second unit was used.

The results are shown in Figure 2 and indicate that the methanol-fueled, turbocharged, four cylinder engine gave power output comparable to that of the stock, gasoline-fueled, naturally aspirated, six cylinder version of the same engine at speeds above 2,000 rpm. It was felt that this curve represented a reasonable achievement for the purposes of this study.

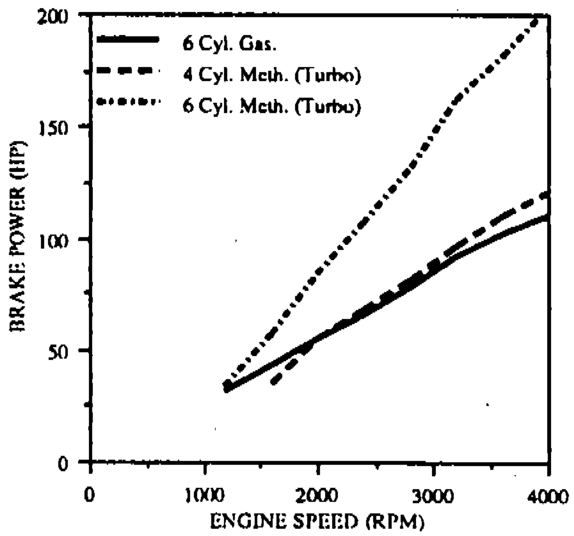

Figure 2. Engine performance

Also shown in Figure 2 is a power curve for the six cylinder turbocharged methanol version of the engine used in the Methanol Vehicle Challenge (Hodgson 1990).

While the particular vehicle used in the study was equipped with a manual transmission, if the vehicle had been equipped with an automatic transmission, the engine would seldom operate at wide-open throttle at engine speeds less than 2,000 rpm.

With the above results obtained, the engine was then installed in the vehicle for road testing. Despite the fact that the deactivation of the two cylinders resulted in uneven firing intervals, the engine operated smoothly and (because the deactivated cylinder valves remained closed at all times) there was no exhaust sound that one would normally associate with misfiring cylinders.

What was apparent with the manual transmission, however, was the loss of engine torque at engine speeds below 2,000 rpm. This was particularly noticeable when accelerating the vehicle from a stop. As mentioned above, however, it is believed that this would not be a problem in a vehicle equipped with an automatic transmission and torque converter.

During testing at steady vehicle speeds of 45, 55, and 65 miles per hour, the intake manifold vacuum values were as shown in Table 1. As expected, the 4-cylinder engine requires less throttling than the 6-cylinder version, when propelling the vehicle at the same speed. The throttling losses (power) are proportional to the product of engine displacement, engine speed and intake manifold vacuum. Table 1 also shows the throttling losses relative to the four-cylinder engine operating at 2350 rpm. Due to a unique combination of the variables the relative numbers shown are of the same order of magnitude as the actual throttling losses in horsepower.

Acceleration Testing

Although the engine dynamometer tests clearly indicated that the engine was delivering the same (or slightly greater) brake power than the base engine, acceleration tests were conducted to document the vehicle performance. Since previous acceleration testing (Larson 1991) had involved 0-500 feet tests, it was decided to use this distance for the tests.

Tests were conducted at a local facility using a timing device based on vehicle-mounted infrared source and detector incorporating a timer. The timer was triggered to start and stop when the vehicle passed reflectors positioned at the start and at the 500 foot locations.

Since the acceleration results are driver-specific, several runs were made using the same driver. The acceleration rates coming "off the line" were traction limited and the results showed some scatter. Based on these results, the 0-500 feet acceleration time for the four-cylinder vehicle was found to be 10±0.15 seconds. For the 6-cylinder vehicle the corresponding time was 10±0.25 seconds.

The acceleration testing verified that the converted vehicle had essentially the same acceleration performance as the base vehicle

Emission Tests

Although the focus of this study was not on reduced emissions, the emission values were generated as part of the FTP testing to measure fuel economy and are shown in Table 2. The test gave results that suggested

Table 1. Intake Manifold Vacuum

Vehicle Speed (mph)	Engine Speed (rpm)	Intake Manifold Vacuum (in Hg)		Relative Throttling Loss	
		4-Cylinder	6-Cylinder	4-Cylinder	6-Cylinder
45	1650	11	16	1.2	2.2
55	2000	9	14	1.2	2.3
65	2350	6.5	13	1	3.0

Table 2. Emission Test Results (gm/mile)

HC	0.40
NOx	0.99
CO	5.17
CO_2	395

the engine was operating rich (high carbon monoxide, low oxides of nitrogen). Since the objective of the testing was to measure fuel economy and since the test clearly indicated that the results were not biased towards high fuel economy by running the engine lean, it was decided to use the fuel economy results with the realization that, if anything, the fuel economy may have been biased slightly in the low direction.

Fuel Economy Testing

Four measures of fuel economy were used in this study: test track fuel consumption tests at 45, 55, and 65 miles per hour; highway testing at 55 mph; fuel economy during emission testing using the Federal Urban Test Procedure and fuel economy during emission testing using the Federal Highway Test Procedure. Each is discussed below.

For the on-road tests the warmed-up vehicle was driven at constant speed for a predetermined distance. The fuel tank was filled prior to the test and then the amount of fuel required to re-fill the fuel tank was carefully measured.

The vehicle speed and the distance traveled were measured using a Labeco fifth wheel. Tests at 55 mph were conducted on a relatively flat interstate highway, but traffic density made tests at 45 mph and 65 mph inadvisable. As a result, tests were conducted on the 7.5 mile long high speed test track at the Transportation Research Center of Ohio. The results of the road testing are shown in Table 3 along with data reported from the control vehicle used in the 1990 Methanol Challenge competition (Larson 1991). In providing the "gasoline equivalent" fuel economy, the conversion factor of 1.754 was used to put the results on an equal energy basis (CARB 1988). That is, the gasoline-equivalent fuel economy (MPG) is 1.754 times the M85 fuel economy (MPG).

Fuel economy results were also obtained from emission testing conducted at the Environmental Protection Agency facilities in Research Triangle Park, North Carolina. The

Table 3. Fuel Economy Results

Test Condition	6-Cylinder Gasoline			4-Cylinder M85
	(1)*	(2)*	(3)*	
Highway @ 55 mph	37.2	n/a	n/a	41.1-43.4
Test Track @ 45 mph	38.6	40.1	n/a	44.1
Test Track @ 55 mph	34.9	32.5	n/a	39.4
Test Track @ 65 mph	31.2	29.2	n/a	32.2
FTP City	n/a	19.9	21.1	23.9
FTP Highway	n/a	35.8	37.3	42.4

*(1) Six cylinder gasoline base vehicle
(2) "Control" vehicle used in Methanol Challenge (Larson 1991)
(3) EPA certification results, 1988 Corsica (Larson 1991)

fuel economy values in these tests were determined by a carbon balance technique in which the amount of fuel used is calculated by accounting for all the carbon discharged from the exhaust (in the form of carbon dioxide, carbon monoxide, and hydrocarbons) and assuming that all the carbon in the exhaust came from the fuel. Knowing how much carbon there is in M85 (1314 grams per gallon) allows the volume of fuel consumed to be calculated (CARB 1988). In these tests, however, the carbon contained in any aldehydes and in any methanol not measured by the hydrocarbon analyzer (FID) was not accounted for. These systematic errors, however, are believed to be very small.

The results of these tests are also shown in Table 3 along with the values from the control vehicle used in the Methanol Challenge and the EPA certification values for the 1988 Chevrolet Corsica (Larson 1991). Note that the certification results are slightly higher than the values measured from the Methanol Challenge control vehicle. The fuel economy results are also shown graphically in Figures 3 and 4. The numbers in parentheses above the bars are the percent improvement in the fuel economy of the four cylinder concept over the reference vehicle used in each figure. In Figure 3 the reference vehicle for steady speed tests is the six cylinder gasoline fueled base vehicle, and the reference for the FTP fuel economy results is the EPA certification data. In Figure 4 the reference vehicle is the "control vehicle" used in the Methanol Challenge, a 1989 production Chevrolet Corsica (Larson, 1991).

Conclusions

Based on the above results it is concluded that it is possible to exploit methanol to achieve improved fuel economy rather than improved

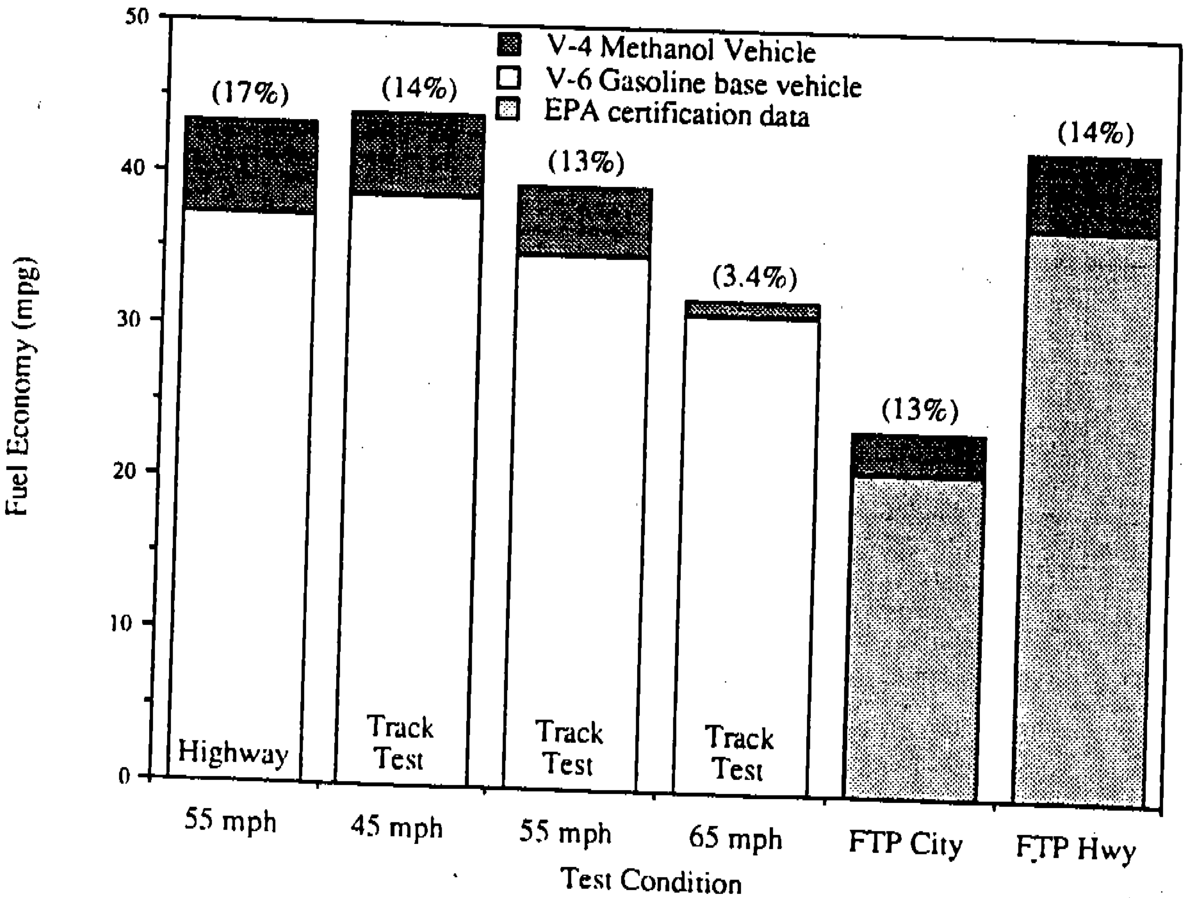

Figure 3. Fuel economy results

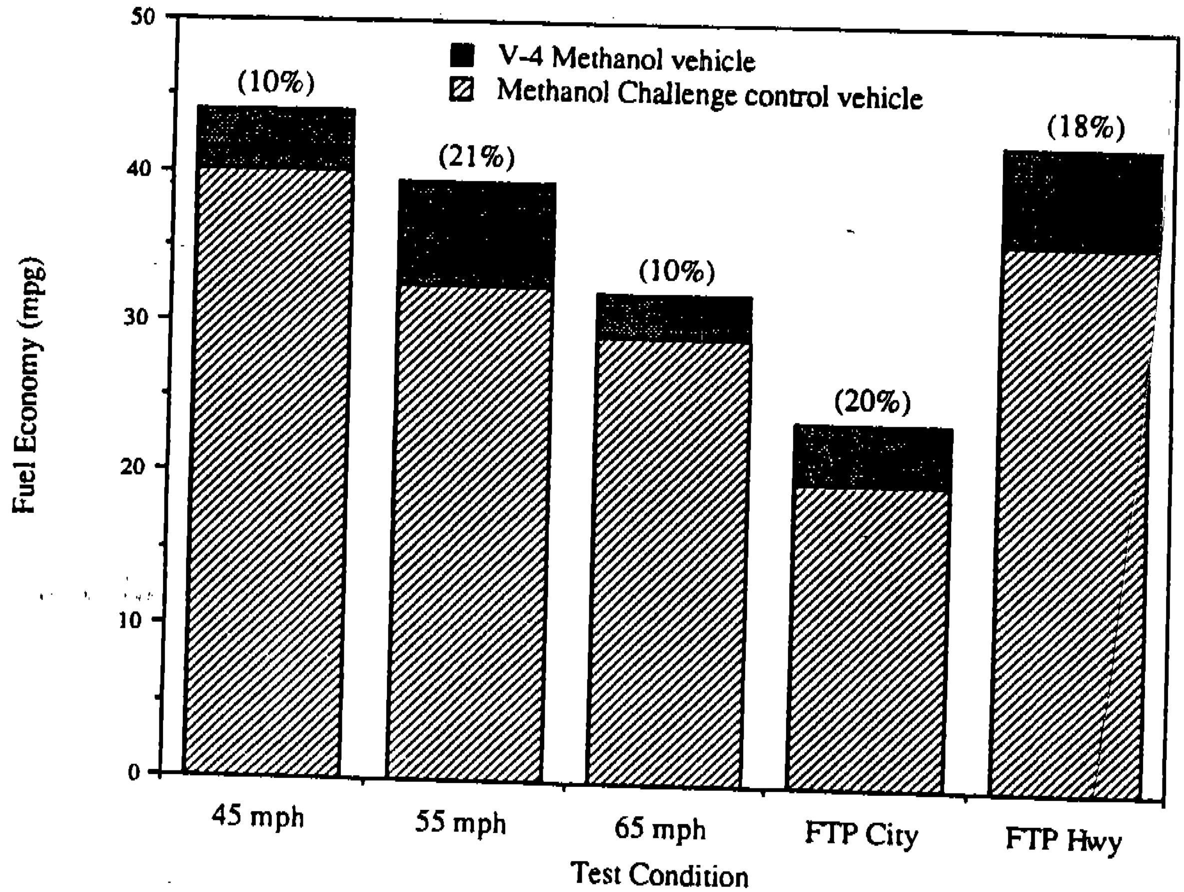

Figure 4. Fuel economy results

performance when compared to a gasoline-fueled baseline vehicle. The strategy of using a smaller displacement engine with charge boosting resulted in fuel economy increases of up to 21 percent at steady highway speeds and almost 20 percent on the FTP City and Highway driving cycles.

The use of a single turbocharger to create the charge boosting, while effective at higher engine speeds, may not be as effective as mechanically driven superchargers or more advanced turbocharger concepts that would result in improved low speed torque output.

Although the concept relies on the properties of M85 for its success, it could be incorporated into flexible-fuel vehicle concepts. Such vehicles, however, would have reduced performance when operating on gasoline because the octane rating and the cooling effects of gasoline are lower than those of M85 and this would reduce the levels of charge boosting and/or compression ratios employed.

Recommendations

Based on the results of this study, it is recommended that the concept be explored further by implementing it in a manner that would be more representative of the technology involved in production vehicles. That is, since the proof of concept has been demonstrated, an existing vehicle could be retrofitted with a smaller displacement engine having a different design from its original engine.

Acknowledgments

Appreciation is expressed to the U.S. Department of Energy for supporting this study through the National Renewable

Energy Laboratory (NREL). The authors would also like to express appreciation to Dr. Kenneth T. Knapp of the U.S. EPA for his willingness to conduct the emission testing on this project. Thanks are also extended to the personnel at the Transportation Research Center of Ohio for their hospitality during fuel economy testing and to the Garrett Division of Allied Signal Corporation for donating the turbocharger used during this study. Finally, thanks are also offered to Mr. Jeff Rohe of AC Rochester for providing advice and support to overcome injector and fuel pump failures encountered during the testing program.

References

CARB, "Alçohol Fueled Fleet Test Program - Eighth Interim Report", ARB/MS-88-05, Mobile Source Division, California Air Resources Board, June, 1988

EPA, "Analysis of the Economic and Environmental Effects of Methanol as an Automotive Fuel", Special Report, Office of Mobile Sources, Environmental Protection Agency, 1989.

Hellman, K. H., "Adjusting MPG for Constant Performance", note to Charles L. Gray, Jr., Environmental Protection Agency, May, 1986.

Hodgson, J.W., et al.,"Methanol Innovation - Technical Details of the 1989 Methanol Marathon - The University of Tennessee", In SAE Special Publication SP-804, Society of Automotive Engineers, 1990

Hodgson, J.W., et al., "The University of Tennessee Methanol Corsica - Engineering for Low Emissions, High Performance", SAE Paper No.902100, Society of Automotive Engineers, 1990.

Larson, Robert P. and Norman W. Hill, "The 1990 Methanol Challenge: Summary of a Successful Student Design Competition," SAE Paper No. 910570, Society of Automotive Engineers, 1991.